proof of fertility of ideas, of organising powers, and of resource and initiative. Research could be so thoroughly well organised that suitable workers would be jointly engaged with those problems for the speedy elucidation of which there is the greatest need, and the results of their investigations would be at the disposal of all British manufacturers. It rests with us to keep these ideas before the mind of the public, now that at last it is ripe to consider them. "Be wise to-day; 'tis madness to defer."

And now I must pass on to my latest task—perhaps the most fateful of all the tasks I have ever undertaken. I bid a sincere regretful farewell to my official colleagues of the Royal Society, whose unfailing and courteous help in my discharge of the duties of the presidential office I gratefully acknowledge. I deeply appreciate the honour conferred on me during the last two years, and if I may utilise "an intelligent appreciation of events before they occur" I heartily congratulate the Society on its election of my successor. We all know, and the world knows, the lofty place held by Sir Joseph J. Thomson in the august realms of science—and we all must feel that our Society could not have selected a more suitable and distinguished President.

On a Method of Estimating Distances at Sea in Fog or Thick Weather.

By J. Joly, Sc.D., F.R.S.

(Received October 20, 1915.)

The problem of estimating distances at sea in fog or thick weather is obviously one of much importance to navigation. Notwithstanding the more perfect means of communication between ship and shore, or between ship and ship, which recent scientific advances have secured, and which are at the command of the more important ships and lighthouse stations at the present time, I can find no reference to the fact that these improved means of communication suffice to solve the problem referred to under a great variety of circumstances. In the present paper I shall confine myself to the determination of distance between ship and shore. In a subsequent paper I hope to discuss the application of the methods involved to finding the distance between ship and ship, and thereby lessening risk of collision.

The method I have to propose is based generally on the differing velocities

of signals in different media: (1) luminous or "wireless" signals (electro-magnetic disturbances) may be regarded as instantaneously propagated over the distances concerned; (2) submarine sounds—*e.g.*, bell-strokes under water—travel in the water at the rate of about 1400 metres, or 4700 feet per second; (3) aërial sounds move at the rate of about 330 metres, or 1100 feet per second. Explosive signals travel somewhat faster in water and air.

Now, if simultaneously emitted signals are sent out in two differing media, the gain of the faster upon the slower travelling disturbance will be proportional to the distance travelled. Hence a ship picking up such simultaneously emitted signals can at once estimate her distance from the signal station from which they originated.

For instance, if a submarine bell be struck simultaneously with another bell which is above the surface of the sea, the relative displacement in time of the two signals will have amounted to 4·3 seconds at a distance of 1 nautical mile. At 5 miles it will be 21·5 seconds. The navigator, listening to the submarine sounds in the telephone, and provided with a seconds watch, easily estimates the interval separating these from the aërial sounds to $\frac{1}{2}$ second. But this time lag corresponds to a distance of about 700 feet, or 117 fathoms. Closer readings of time are possible with many sound signals. Hence it is evident that the method proposed will give results enabling distances to be measured with an accuracy more than adequate to the objects in view.

A simplification in the nature of the observations required on board the ship, which possesses many advantages, may be secured by regulation of the signals. Thus we may arrange for the submarine signals to be sent out at intervals, which are definitely timed. There might be one bell-stroke every 2 seconds (as sometimes adopted at present), or even one bell-stroke per second. These signals are sent out in groups. There might be 30 successive strokes, followed by an interval of silence of half a minute. Simultaneously with the first stroke of each group the air signal is made. This convention is known to the mariner, and, when the first stroke of each group of bell-strokes is heard on the ship, he has only to count up the strokes till he hears the sound signal transmitted through the air in order to determine his distance from the signal station. Thus, if the bell-strokes are timed one per second, the air signal reaches a ship 1 mile away a very little after the fifth stroke of the bell. If the bell-strokes are timed every 2 seconds, the air signal coincides nearly with the third stroke of the bell, coming about $\frac{1}{3}$ second later. On this system the use of time-measurers on board ship is not required. The signals themselves tell the mariner his

distance from the shore. The degree of accuracy secured is ample for the safety of his ship.

It will be evident that the grouping of tbe submarine signals on the lines suggested above may be distinctive for the station, and in thick weather may render its identification certain.

Wireless telegraphy is so generally at the disposal of ships at the present day that signals transmitted by its aid might well be used to supplement the submarine and air signals. There would be, then, signals simultaneously sent out in the three media. The special value of this would be that, in the event of particular atmospheric conditions interfering with the propagation of sound in the air, the approaching vessel can always judge her distance by the lag of the submarine signal on the ætherial. The sensitiveness here is about 1·2 seconds to the nautical mile. A knowledge of her distance from the signal station of less than $\frac{1}{2}$ mile would be in most cases easily obtained. Again, in this case, vessels which had no auditory apparatus for submarine signals might determine distance by wireless and by air sounds. This combination secures the maximum sensitiveness, *i.e.* about 5·5 seconds to the nautical mile. A ship at 5 miles from the signal station receives the aërial sound 27·5 seconds after the wireless signal. Where wireless was already installed at the signal station, the increased cost of sending out periodic signals with it would be insignificant contrasted with the advantages gained. It is, of course, open to choice whether the wireless signal should go out with every sound signal or only coincide with it periodically.

If the mariner can infer the direction in which he receives the sounds, whether in air or in water, and if he determines his distance from the signal station, he, of course, is able to define his position completely. Even if he cannot infer the direction from which the sounds reach him, but if he can lay down his own course upon the chart, his position is determined as one of two possible points by his distance from the signal station. If the sounds from two coastal signal stations are audible to him his position is defined even if he is, to start with, ignorant of his course upon the chart. For in the two distances he possesses the radii of two circles which are centred at the signal stations. Their intersection on the chart gives him his position. Finally there is the possible case (especially if submarine signals are not available) of his knowing neither the direction of the sounds nor his line of advance on the chart and hearing one signal station only. In this case his position is still determinable on the result of successive estimates of distance and a knowledge of his own compass course.

Thus in fig. 1 the ship which is at the position O, and which is heading N.N.E., hears the signals from the coast and determines her distance as d_0

from the signal station. Setting out on paper the course direction N.N.E. and taking any point on this line as the position O, the mariner strikes a circle to the radius d_0. In five minutes, say, he picks up another signal and obtains the distance d_1. He knows the new position of his ship, for he can estimate his own speed. This gives him the point marked 1. From this point a circle is struck to the radius d_1. This circle intersects the first circle on two points, P and S. These, in general, lie the one to port the other to starboard. If d_1 is greater than d_0 the two points lie aft; the ship is going away from the station. If d_1 is less than d_0 the conditions are reversed and she is nearing the station. The mariner knows that the signal station lies on

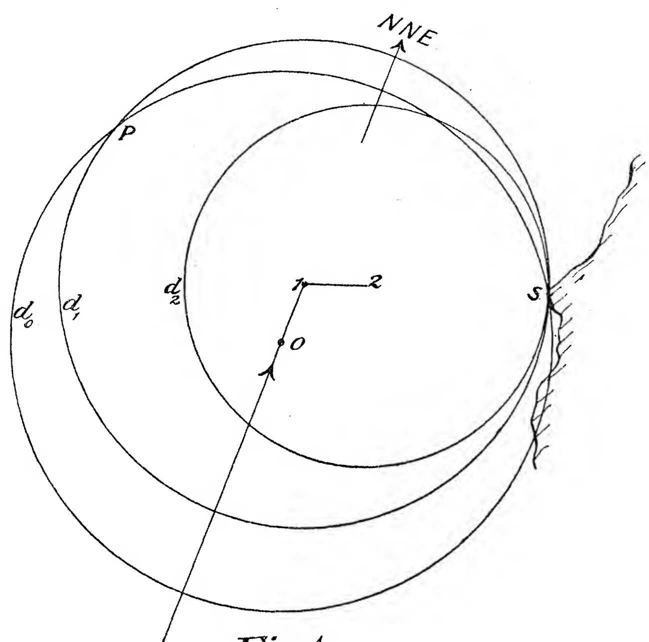

Fig. 1.

one or other of the points P and S. He may decide between them by altering his course towards one of the points till he picks up a third signal. He is now at 2 and obtains the distance d_2. The circle to radius d_2 decides the question. In general the position is determined according as d_2 is greater or less than d_1. Having got the bearing of the signal station and its distance, his own position is fully known. There are two special cases when he can determine the bearing of the station without altering his course; when his ship is heading directly towards or away from the station. For in these cases the increase or diminution of the distance as given by any two signals will conform to the ship's run in the interval.

We have assumed above that the timing of the signals is not effected closer than to $\frac{1}{2}$ second. As already stated this corresponds to an accuracy of 700 feet in the determination of distance. For all practical purposes this would suffice and, indeed, might be said to be needlessly precise. It is, however, worth pointing out that, even by unpractised observers, closer results would probably be obtained. For the error in effecting the readings is always of the same sign. What error there is must arise from operating the stop-watch after the exact moment of passage of the sound wave. Here the personal equation of the observer and any mechanical lag in the instrument are responsible for the delay. But both observations—that of starting and of stopping the seconds hand of the watch—are affected in the same manner by this source of error. It is the difference between the two readings we take for our calculation. The error, therefore, tends to be reduced or actually eliminated. In the case of practised observers it would probably be very nearly eliminated.

In high winds an error arises from the convection of the sound disturbance with the medium. This is not, under any ordinary conditions, important. It can in any case be allowed for. A wind blowing at the velocity of 40 knots, or say 60 feet per second, introduces an error which may be positive or negative in sign and may attain to about 5 per cent. This would be, in most cases, negligible. The variation of the velocity of sound with the temperature of the air is also capable of correction, but is so small as scarcely to call for consideration. Between 0° C. and 15° C. the velocity has been found to vary from about 330 metres per second to 340 metres per second. If neglected this introduces an error of but 3 per cent. The velocity of sound in air or in water is greater than normal if the sound is explosive in origin. The special rates for explosions in air and in sea water have been recorded and if desired may, of course, be used.

For accurate timing of sound signals the nature of the sound must be abrupt, either upon starting or stopping, or of brief duration. Ordinary gun-fire signals are readable to a fraction of a second even at a distance of five or six miles. The effect of distance is to blur the definition, but it is to be remembered that at considerable distances this matters little. One second error in our readings introduces an error of one quarter mile. In five miles this would, obviously, matter little.

If the methods herein advocated were brought into use, a very little training introduced into the courses for Master's and Mate's certificates would render all the operations required easy and certain. The amount of skill required is of the smallest. Tables reducing time-intervals to distance, for ordinary and for explosive sounds in water and air, with simple statement of corrections,

and even time-measurers reading directly to distances, might be used to further simplify what is already a simple operation.

It is surely needless to labour the question of the importance of this addition to the usefulness of lighthouse stations round our coasts. The nature of the alterations required at any station or lightship will, of course. depend upon the existing equipment. The electrically operated submarine bell and any explosive air signal operable by electric firing—for instance the acetylene gun—are especially adapted to the emission of synchronised signals. Signals electrically operated may be rendered periodic by a simple clockwork mechanism to distribute and regulate the contacts. Wireless signals naturally fall into the same category. In other cases mechanical or pneumatic connection could generally be introduced without serious outlay. The nature of the problem is, of course, determined by the particular nature of the machines, which have to be regulated to unison, and is not a general one.

But all outlay of money and labour must be considered in relation to the advantages gained. Navigation in fog and thick weather would gain both in speed and safety if the mariner, as his ship advances, knows his distance from the coast. This is more especially the case where important landfalls are made, but it applies with almost equal force to every important harbour and every dangerous coastal feature of our shores.